# Designing a structured activity platform to scaffold complex skills

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**Abstract:** Secondary school students must learn to solve complex, ill-defined problems, but providing formative feedback imposes an intractable orchestration burden on teachers. Peer feedback and discussion systems can reduce this burden, but little is known about the design constraints associated with adopting such a system in the classroom. In this design research project, we iteratively developed and piloted a web-based system for open-ended writing activities through interviews and classroom pilots with 36 teachers and 562 students at middle and high schools across the United States. By adapting techniques from both traditional and technology-enhanced discussion and feedback settings, our prototype enables teachers to conduct scalable, semi-synchronous classroom activities aimed at developing specific complex problem-solving skills.

**Keywords:** design-based research, scripting, secondary school, ill-defined problems

## Introduction

*Ill-defined problems* require extended inquiry, creativity, and self-regulation to define and solve (Chi & Glaser, 1985; Webb, 1999). As middle and high school curriculum standards require these forms of analysis (Common Core State Standards Initiative, 2018), supporting students in developing complex problem-solving skills represents a key research and design challenge for the CSCL community (Jonassen, Lee, Yang, & Laffey, 2005). While individualized expert feedback can teach these skills effectively (Stein, Engle, Smith, & Hughes, 2008; Brookfield, 2011), scaling this feedback to large numbers of learners imposes an intractable orchestration burden on educators. For well-defined or procedural problems such as those commonly found in arithmetic or algebra, intelligent tutoring systems may provide learners with automated feedback based on the system's model of misconceptions, or a mapped set of all possible student responses. Unfortunately, intelligent tutoring systems are expensive to develop, highly domain-specific, and cannot provide feedback on ill-defined problems where student responses are unconstrained.

In the classroom, teachers may attempt to increase student participation in classroom discussion as a method of engaging with ill-defined problems. To that end, orchestrating and supporting student discourse has been a focus across many subject areas in recent decades. (Cazden, 2001; Sfard & Cobb, 2014). With the growing availability of classroom technology, teachers may additionally leverage tools to supplement discussions and increase participation (Brookfield & Preskill, 2012). Yet online discussions often fail to elicit deep thinking and meaningful participation from students (Christopher, Thomas, & Runnels, 2004), even when educators provide initial prompts and intervene with occasional replies (Mazzolini & Maddison, 2007). An online learning environment provides highly structured ways for students and teachers to communicate, but may not correspond to more traditional pedagogical scripts.

In this design research project, we explore how features of peer discussion and feedback systems might facilitate the development of specific complex skills in a classroom setting. Through interviews and classroom pilots with 36 secondary-level educators and 562 students across the United States, we iteratively developed an online system for open-ended, teacher-led classroom activities. Unlike prior work, our prototype facilitates *semi-synchronous* activities, in which all students participate simultaneously and engage with each others' work, but progress through the activity at their own pace. Our design introduces a matching procedure that uses expert-authored model work to eliminate wait time for students. We synthesize our findings into a set of design insights for similar systems, focused on reducing the orchestration burden for teachers and structuring student interactions around specific complex skills in a domain-agnostic fashion.

## Background

### Group discussion

Student centered group discussions can offer social constructivist scaffolds which support students in solving ill-defined problems (Vygotsky, 1978; Ge & Land, 2004). Intentional structures can communicate content ideas between students and the teacher (Yackel and Cobb, 1996) or facilitate unique avenues of feedback such as peer tutor observing their tutee's use of new knowledge (Okita & Schwartz, 2013). A variety of strategies exist to attend to such structures, but discussions are challenging for instructors to orchestrate, particularly at secondary levels (Stein et al., 2008; Brookfield, 2011; Palincsar and Brown, 1984). And discussions can remain shallow with insufficient teacher structuring (King, 1999).

Many teachers leverage asynchronous online discussion platforms to lower these facilitation orchestration costs (McConnell, 2000) and gain wider participation (Brookfield & Preskill, 2012; Hammond & Wiriyapinit, 2005). Asynchronous discussion offers a number of benefits beyond reduced orchestration cost. Students can spend more time thinking about their contributions (Meyer, 2003), students can return later to reflect and revise (Salmon, 2002), and students can increase their work's visibility by contributing in multiple threads concurrently (Groeling, 1999). Yet online discussions often fail to elicit deep thinking and meaningful participation from students (Christopher, Thomas, & Runnels, 2010; Schrire, 2006; Lipponen, Rahikainen, Lallimo, & Hakkarainen, 2003), even when educators provide initial prompts and intervene with occasional replies (Mazzolini & Maddison, 2007). Many discussion platforms incorporate features designed to provide pedagogical structure and scaffolding (Jeong & Joung, 2007; Guzdial & Turns, 2000). However, these platforms generally cater to specific domains, do not allow teachers to customize activities to target particular skills, or require teachers to provide additional instructions to adapt usage for the classroom.

### Peer feedback

Peer review allows students to receive individualized feedback without imposing a reviewing burden on teachers. Students may find it easier to incorporate feedback from their peers, particularly when teachers fall prey to expert blind spots and fail to explain concepts that are not obvious to novice learners (Ambrose et al., 2010). Providing feedback exposes students to alternate solutions and approaches, strengthens students' ability to reflect on their own work (Hansen & Liu, 2005; Ambrose et al. 2010), and has been shown to benefit reviewers even more than recipients (Okita and Schwartz, 2013), particularly for lower-proficiency students (Lundstrom & Baker, 2009).

Absent the appropriate scaffolds, however, students often struggle to provide and incorporate feedback successfully. Effective feedback should help students gauge the quality of their work and define goals to direct subsequent efforts (Ambrose et al., 2010). Compared to teachers, however, peer reviewers identify fewer problems with written work and provide fewer concrete suggestions for improvement (Cho, Schunn, & Charney, 2006). Online peer review systems such as SWoRD and PeerStudio demonstrate the potential for CSCL environments to scaffold the exchange of peer feedback at scale. By matching reviewers to submissions, these systems allow students to receive feedback more quickly and from multiple peers, which can rival or exceed comments from a single teacher in helpfulness (Cho et al., 2006; Kulkarni, Bernstein, & Klemmer, 2015).

## Method

### Design-based research methodology

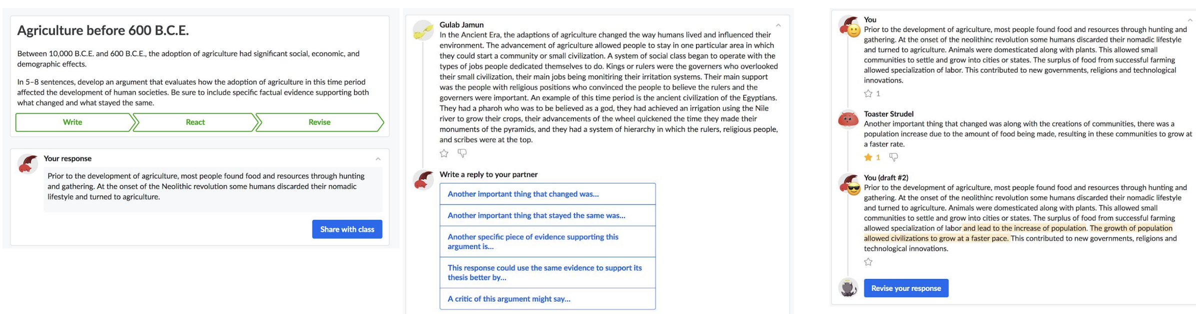
Despite substantial prior research on peer discussion and feedback systems in higher education and MOOCs, there is a lack of understanding around how such systems might augment teacher-led classroom activities in domains beyond mathematics and science. For instance, many high school teachers are encouraged or required to align their teaching to curriculum standards such as the Common Core or Advanced Placement. These curricula often prescribe learning outcomes in terms of complex skills a successful student should be able to perform, such as analyzing patterns of historical cause and effect, or identifying the impact of figurative language in a literary text.

In order to understand the orchestration challenges associated with middle and high school classroom activities, we employed a design-based research methodology (Edelson, 2002), collaborating with 36 educators in social studies, English language arts, math, and science over 15 months to co-design iterations of a functional prototype. We deployed our prototypes in 13 of these teachers' classrooms in 26 distinct pilots. For 14 of these pilots, we visited the classrooms, executed the activities in collaboration with the teachers, and observed students during the activity. For the remaining 12 pilots, we worked with teachers to deploy the activities remotely in their classes; we observed student behavior via timestamped logs of their inputs and sent students and teachers post-activity surveys. Four of the remotely-deployed pilots were completed partially or entirely outside school as an homework assignment, and the rest conducted as in-class activities. In total, our pilots involved 562 students at 12 U.S. secondary schools (9 public, 2 charter, 1 private) across 6 states.

The iterations reported in this paper represent a preliminary stage of design-based research; our empirical methods emphasize qualitative feedback, observation, and interviews appropriate for narrowing the design space and iterating at low cost. Future stages would attempt to validate these design principles through more controlled experiments and quantitative evaluations.

## Activity description

We piloted a sequence of web-based activity systems designed to scaffold skill-aligned, domain-agnostic, scalable collaborative learning by reimagining practices from classroom discussions in a semi-synchronous context. While each iteration refined our design principles and implementations, all prototypes facilitated the same core activity structure. First, we worked with teachers to co-design an open-ended activity prompt based on a specific ill-defined problem-solving skill. Next, students *submitted* responses to the prompt (Figure 1a), *engaged* with peer and model submissions using procedural scaffolds (Figure 1b), and *revised* their original submissions based on peer feedback (Figure 1c).




(a) (b) (c)

Figure 1. Students (a) *submit* responses to ill-defined problems, (b) *engage* with peer and model work using procedural prompts, and (c) *revise* their original response.

Students accessed our interface through a link provided by their teacher; the link was unique to each classroom and to the activity co-designed with the teacher. Schools varied widely in technology access, so we designed our systems to support laptops, tablets, and mobile phones.

### Submitting responses to ill-defined problems

Students begin by individually drafting a response to an activity prompt provided in the system interface (Figure 1a). Teachers designed these activities to require 5-7 minutes of response time, but students were not constrained in this regard. One representative activity posed a question reviewing the Neolithic Period:

> Between 10,000 BCE and 600 BCE, the adoption of agriculture had significant social, economic, and demographic effects. In 5-8 sentences, develop an argument that evaluates how the adoption of agriculture in this time period affected the development of human societies. Be sure to include specific factual evidence supporting both what changed and what stayed the same (Adapted from College Board, 2017).

### Scaffolded engagement with other responses

Next, the system displays a different submission for the same activity and prompts the student to engage by writing a reply (Figure 1b). Our final iterations scaffold replies by providing a selection of procedural prompts, which teachers can customize to engage important aspects of the activity's targeted skill. In the example activity described above, the student might choose the "Another important thing that stayed the same…" prompt and continue by writing another historical detail not mentioned in the current response. In our pilots, students repeated this step 2-3 times in order to engage with a variety of submissions. Later prototype iterations allowed students to add reactions to submissions, using a "gold star" to indicate great work and a "thumbs down" to flag submissions for teacher attention.

### Incorporating replies through revisions

After students write replies to several peers, the system invites them to revise their original submission (Figure 1c). To support the revision process, the interface displays replies received from other peers in real time. Later iterations of our prototype allowed students to browse their classmates' submissions and replies at this stage. Students may submit multiple revisions; our interface highlights the changed text in each new draft. After each revision, students privately report confidence in their work by selecting an emoticon.

### Real-time teacher facilitation

As students progress through the activity, the system aggregates threads of submissions, replies, and revisions in real time for teachers (Figure 2). Each thread displays the sequence of confidence ratings reported by the original author. Revisions are highlighted in yellow, and "gold star" and "thumbs down" peer reactions identify submissions that merit further attention. Teachers can use the report to monitor student participation and facilitate in-class discussions of particular exemplars or pitfalls. Following the activity, teachers review the report to ensure completion, spot-check, and follow up with particular students as needed.

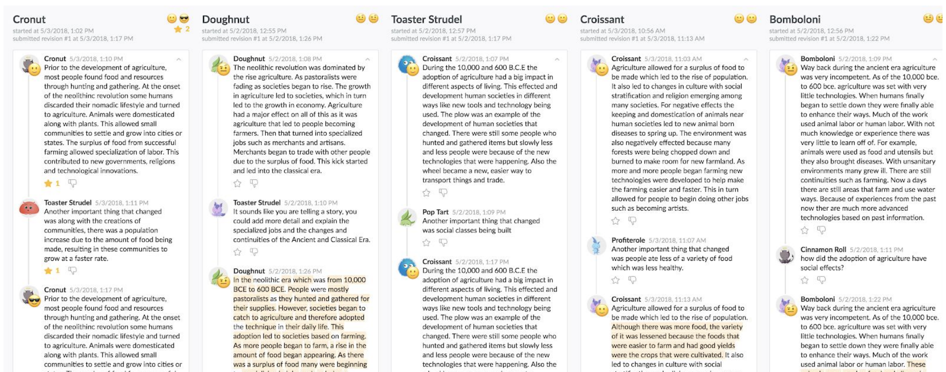



Figure 2. Our prototype interface aggregates student submissions, replies, and revisions in real-time to support teacher monitoring and review.

## Design iterations and insights

Our prototype illustrates how elements of asynchronous discussion and feedback systems can complement teacher-led classroom activities to develop complex skills. In this section, we elaborate on the underlying characteristics and mechanisms of our system that emerged through the iterative design process. The goal of our system is to facilitate semi-synchronous activities that are:

1. *Skill-aligned:* Teachers can design free-response activities to target specific complex problem-solving skills, such as "analyzing continuity and change over time."
2. *Domain-agnostic:* None of the system's core mechanisms should be specific to a particular topic of instruction. Teachers should be able to design activities targeting complex skills in any domain, including history, language arts, mathematics, and science.
3. *Scalable:* Activities should scale to large classrooms, providing all students with equal opportunities for participation without substantially increasing the orchestration burden for teachers.

### Combining peer work with expert-authored model work

Dealing with variation in submission quality is a difficult problem in peer feedback systems. In early pilots, many students did not demonstrate clear learning gains from engaging with peer submissions unless those submissions were exemplary. This was particularly true for students who struggled with the initial activity prompt: neither the feedback they provided to others, nor their own revisions, demonstrated improvements in the target skill. Based on these observations, we incorporated expert-authored *model work* into the peer engagement phase, with student engaging with one peer-authored submission and one expert-authored submission. Models of target performance—and, conversely, weak performance or common misinterpretations of the assignment—have been used to scaffold goal-directed practice (Ambrose et al., 2010). Teachers also expressed interest in using model work to assess understanding and tailor activities to learning outcomes, such as by asking students to fix a submission with a particular weaknesses, or score a response according to a standard rubric.

Our final interface did not distinguish between peer and model submissions, and all identities were anonymized. We chose not to reveal model submissions as such for two reasons. First, prior work has shown that the mere belief of learning in a social context may improve learning outcomes (Okita, Bailenson, & Schwartz, 2008); model work can appear inauthentic and decrease the perception of social interaction. Second, identifying model work in the interface can have unintended consequences: students may directly copy an exemplary response into their own revision, or disengage from providing elaborative feedback because there is no recipient or because they consider the work perfect as-is.

After incorporating model work, students in subsequent pilots engaged authentically with these submissions by providing elaborative feedback aligned to the activity's focus skill, and incorporating components of the submission into their own revisions without resorting to wholesale plagiarism.

## Eliminating wait times

Unlike traditional large-group discussions, asynchronous discussion systems allow students to spend time reflecting and revising (Meyer, 2003; Salmon, 2002) across multiple concurrent threads (Groeling, 1999). In order to capture these benefits in a synchronous classroom activity, systems must provide equal opportunities for students to participate, regardless of differences in task completion speed. Orchestrating our *submit, engage , revise* workflow raises challenges at each transition: first, ensuring a student can begin responding to others after completing their initial submission; second, ensuring a student can revise their original work based on responses from peers.

In our early pilots, all students advanced from one stage to the next as a group. Because students finished each step at different rates, some students were always left waiting for their classmates. We observed these students quickly disengage by switching to other browser tabs or doodling in notebooks. Some became frustrated, tapping repeatedly on the disabled "Next" button.

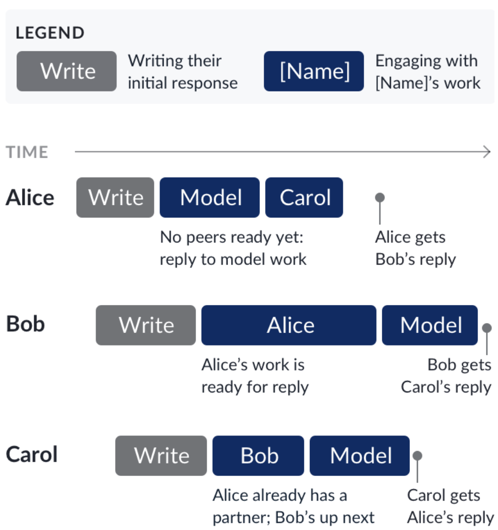



Figure 3. An illustration of our orchestration system.

Our final prototype addresses these pain points with a novel matching procedure, which relies on model work to allow students to progress from submission to engagement without waiting for their peers. Figure 3 shows an example of our procedure with three students named Alice, Bob, and Carol. Alice is the first to complete her submission. Since there are no other peer submissions awaiting review, she moves on to engage with model work. Next, Bob finishes his submission and engages with Alice's work. Carol is the last to submit, and engages with Bob's work. When Alice finishes with the model work, she is given Carol's work for her second engagement task, ensuring all student submissions have been seen by a peer. After completing their peer reviews, Carol and Bob each engage with the model work as well. More generally, our system maintains a queue of unseen peer submissions; when a student completes their initial submission, their work is added to the queue, and they begin engaging with the submission at the front. If there are no others to review, the student engages with model work.

We used this matching procedure in our later pilots, resulting in zero student wait times and all student work distributed for peer response. Unlike more conventional work-trading pairs or round-robin groups, our approach ensures the slowest student's work is seen by a peer without requiring that peer to wait. Instead, that peer can first engage with model work to allow the slowest student more time for completion.

While incorporating model work smooths the transition from initial submission to responding to peers, students may still reach the revision stage before receiving peer responses. Early iterations of our prototype permitted students to begin revising while awaiting these responses, but some students expressed a preference for continuing to interact with classmates' work in this situation. As a result, our subsequent iterations allowed students to either revise their own work or engage with additional peer submissions while waiting for responses. We re-designed the revision interface to support multiple drafts, and encouraged students to revise again after seeing others interact with their work. After this change, many pilot students submitted multiple drafts, with later drafts incorporating observations from their peers.

Procedural prompts should target specific skills and provide agency

Question prompts and other forms of procedural facilitation have been used to guide student attention, facilitate metacognition, and elicit thoughtful elaboration and argumentation (Scardamalia, Bereiter, & Steinbach, 1984). When integrated into discussion software and peer feedback systems, prompts can improve response quality and topic-relevance (Guzdial & Turns, 2000; Kulkarni, Bernstein, & Klemmer, 2015). Building on this work, we explored a wide variety of prompts to understand how best to incorporate this form of scaffolding into the middle and high school setting.

When leading traditional classroom discussions, teachers described tailoring their prompts to elaborate the problem, or elicit further explanation from students (Brookfield & Preskill, 2012). Yet many discussion-based prompts did not translate well to a semi-synchronous activity context. For example, an early activity used the procedural prompt "*I'm not sure what's meant by…*":

Student 1: Industrialization helped expand trade and trade networks to other countries. This was due to an abundance of raw recourses [sic]. This means that trading and trade networks were made throughout the world.

Student 2: *I'm not sure what's meant by* "trade networks." What is a network

Because Student 1 was only responsible for revising their own response, but not answering Student 2, and because the teacher was not present to facilitate the conversation, this particular exchange ended without clear benefit to either student. In general, within our semi-synchronous activity structure, broadly applicable procedural prompts such as "*I'm not sure what's meant by…*," "*I disagree because...*," or "*A strength of this response is…*" failed to reliably deliver benefits to either the giver or receiver of feedback.

In subsequent iterations, we addressed these issues by working with teachers to generate a menu of prompts focused on specific complex reasoning skills rather than free-form discussion. (Figure 1b). Rather than adhering to traditional discussion structures, we viewed the peer engagement stage as an opportunity for peers to construct and elaborate conceptual schema based on other submissions (Ambrose et al., 2010). Examples of skill-based prompts include:

- **Contextualization:** *"One geographical influence to add might be…"*
- **Argument development:** *"A critic of this argument might say…"*
- **Analysis:** *"This claim assumes that…"*
- **Experiment design:** *"One source of error in this experiment might be…"*

Finally, we provided students with 3-5 different skill-aligned prompts to choose from (Figure 1b). By providing students with control over their learning activities, we sought to increase autonomy and motivation (Moller et al., 2006) and allow students to engage at a comfortable level of difficulty. For example, on an activity focused on continuity and change over time, a student might choose to provide feedback that generates more evidence (*"Another important thing that changed was..."* or *"Another important thing that stayed the same was..."*), strengthen the analysis (*"This response could use the same evidence to support its thesis better by…"*), or challenge the thesis (*"A critic of the argument might say…"*).

As a result of these iterations, we saw students give richer feedback and make stronger revisions based on the rich feedback they received:

Student 1: During the time period of 10,000 B.C.E. and 600 B.C.E, there came some changes and continuities. Demographics played a big role during this time period. Population rates skyrocketed at the time as well as fertility rates. One continuity that happened was the fact that people went off as hunter and gatherers, whereas closer to 600 B.C.E. they differed by using other techniques. Also, people continued to use animals as a resource for survival.

Student 2: *A critic of this argument might say* to explain more your statements like "they differed by using other techniques". For example what other techniques ?

Student 1: [adding to original submission] Hunter gatherers differentiate from the Neolithic era because they had many children and were constantly on the move. Agricultural villages and societies developed a surplus of food which allowed them to live in a better home. Civilizations changed as Rome was innovated and developed a cultural stability.

This focus on skill-aligned questions ensured that both giver and receiver engaged with the activity in a way that aligned to the learning outcome of the activity, while permitting but not requiring extensive discussion or teacher facilitation.

## Discussion

Curricular standards increasingly incorporate ill-defined problem-solving skills, informing classroom instruction at the secondary levels. While collaborative learning technologies are well-positioned to support students in developing these skills, Dillenbourg et al. (2011) note that the success of CSCL tools often lies in practical implementation details such as the orchestration load imposed on teachers. Accordingly, we apply a design-based research methodology, working with 36 middle and high school teachers and 562 students to co-create an activity system within realistic classroom constraints. By adapting techniques from both traditional and technology-enhanced discussion and feedback settings, our prototype enables teachers to conduct scalable, semi-synchronous classroom activities aligned to skills.

Current approaches to teaching ill-defined problem-solving often require large projects and expert orchestration. Our prototype demonstrates the feasibility of targeting complex domains through lightweight, scalable classroom activities. Future work should quantitatively validate specifics of our system's design in a controlled experimental setting. Our interviews and pilots highlight opportunities to further facilitate orchestration by enabling teachers to "drop in" on any response to provide feedback of their own, and exposing trends in class writing through lightweight textual analysis. There are also opportunities to use this system to connect distant classrooms and help students see a wider variety of perspectives, as well as reach learners outside of traditional classroom settings.

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